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HF BACKSCATTER STUDY AT 19.4 MHz THROUGH SUBAURORAL IONOSPHERE

by

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Finally, the observed occurrence statistics of FAE(E) and FAE(F) presented in Scientific Report No. 1 are discussed in the context of current theories for the formation of these irregularities.

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1. INTRODUCTION

The object of this study was to determine the effect of the sub-auroral ionosphere on the propagation of HF signals. The results of an earlier study (Basu and Vesprini, 1972, hereafter to be referred to as Report 1) have shown that the ionosphere at these latitudes is far from uniform with field aligned electron density irregularities existing in the E and F region for a fair percentage of the time. Thus, scattering by these field aligned irregularities may cause a diminution or cut-off of the F-region propagated HF signal. Reflection from intense mid-latitude sporadic E may also have a blanketing effect on HF propagation. Both these factors are considered in this study. In addition to magnetic storm effects the quiet time F region itself is known to exhibit various anomalies such as the evening anomaly and seasonal anomaly in the peak electron concentration of the F2 layer. We have attempted to study the effects of these anomalies on F-layer propagation. Another important parameter which may affect oblique HF propagation is the D-region absorption particularly during magnetic storms. However, no attempt has been made to include absorption effects in this study.

A brief review of current theories for the formation of field aligned irregularities has been presented and the observed statistical occurrence characteristics of these irregularities are discussed in the light of the recently developed physical concepts.

2. EQUIPMENT AND DATA REDUCTION

The data for this study were obtained from film records of a continuous series of 19.39 MHz oblique backscatter observations made at Plum Island, MA (42.63°N, 70.82°W and 56° invariant

magnetic latitude) during 1961-65. The data acquisition system as well as the general methods of data reduction have been reported in detail in Report 1.

3. NOMENCLATURE AND IDENTIFICATION OF ECHOES

The backscatter records, in general, showed three main classes of echoes in the northern quadrants:

- i) Ground backscatter echoes propagated via sporadic E reflection
- ii) Ground backscatter echoes propagated via F-region reflection
- iii) Direct backscatter from aspect sensitive field aligned irregularities in the E and F layer and which have been designated as FAE(E) and FAE(F) respectively in Report 1.

Since there is considerable confusion in the literature (Croft, 1972) regarding the nomenclature of the various phenomena observed in conjunction with HF propagation, we shall briefly summarize the various terms used in this report to describe the above echoes.

The term E_s propagation will be specifically used for propagation of signals reflected by an E_s layer and then scattered by the ground so that the signal retraces its path to the transmitter. It was determined that these diffuse echoes which were obtained at delays of 8-10 msec in the northern quadrants could not be direct returns from the auroral E layer as the antenna system used for this study discriminates against the very low elevation angles (0-1 degree) that would be required to obtain such delays for direct backscatter from the E layer. A similar point has been made by Egan and Peterson (1962). More definite evidence that the E_s propagation is actually a reflection from E_s ionization is presented in the next section. Again, it

is not possible for these diffuse echoes to be one-hop F-region propagated groundscatter echoes (to be referred to as 1F echoes); at a frequency of 19.4 MHz 1F echoes occur at much greater delays. Indeed the daytime E_s echoes are usually accompanied by 1F and sometimes 2F echoes at appropriately greater delays. Besides, the continuous operation of the sounder makes it possible to follow the regular diurnal pattern of 1F echoes as they develop in the morning and decay after sunset. The E_s echoes on the other hand, are, as their name implies, rather sporadic in nature and are observed for periods of a fraction of an hour to a few hours.

The aspect sensitive field aligned echoes such as those observed by Peterson et al (1955) showed up as much sharper well defined traces on the films. They were predominantly centered in the NW quadrant and were less frequently observed in the NE. The large beamwidth of the antenna ($\sim 45^\circ$) precluded sensitive enough range-elevation displays which could have determined whether these field aligned echoes were themselves discrete or diffuse in nature. Such a distinction was made, among others, by Leadabrand (1961, 1965) working in the VHF and UHF band with narrow beam radars. Thus in the terminology of the IAGA, 1968 classification (Sverdllov, 1971), we cannot distinguish between B_1 , B_2 and B_3 types of radio aurora. In addition since some of the aspect sensitive echoes are obtained during periods of magnetic calm and hence could not be directly related to auroral disturbances at the latitude ($\sim 60^\circ$ invariant) of sounding, it was decided to refer to them generally as FAE's rather than radio aurora.

4. E_s PROPAGATION

The occurrence characteristics of E_s propagation in the NW and NE over the five year period of observation are presented in Figures 1 and 2 for quiet magnetic conditions. There is no

systematic variation of E_s propagation from one year to another or from one quadrant to another. The only prominent feature is the presence of E_s propagation during the summer months (May through August) of each year. The diurnal variation during these months shows a morning and an evening peak of occurrence. The evening peak is usually the more intense one when E_s propagation is observed for as much as 50 per cent of the time. Some occurrence is seen during the winter months in the evening hours, but it is usually present for less than 10 per cent of the time.

The diurnal variation of the occurrence of E_s propagation over the five years of observation for the NW during quiet magnetic periods is also shown in Figure 3. As in Figure 1, we see the two diurnal peaks of occurrence with the largest peak occurring in the evening. The occurrence of E_s propagation during magnetic storms is too infrequent for any statistical conclusions to be drawn. This could be due to an actual decrease of E_s occurrence during storms, as has been reported by various authors, as well as increased D-region absorption during storms which could cut off oblique E_s propagation since four traversals of the absorbing lower ionosphere are required.

To determine whether this particular type of propagation is indeed a reflection from E_s clouds to the north of the station, fE_s occurrence contours from Ottawa were studied. The ionosonde station at Ottawa is very well suited for a comparison of this kind being situated at a slant range of approximately 540 km (E-layer height) at an azimuth of 330° to the observing station. Most of the median delays for the E_s type propagation correspond to such slant ranges for the E_s clouds. On a range-elevation display, these slant ranges correspond to elevation angles of 8 to 10° . Thus maximum vertical frequencies of approximately 4.5 to 5 MHz for the E_s clouds should be able to reflect the observing frequency. Figure 4 shows percentage occurrence contours of $fE_s \geq 5$ MHz as observed at Ottawa for the years 1961-65. The data for these contours were obtained

from the monthly bulletins of ionospheric data published by the Defence Research Telecommunications Establishment, Ottawa, Canada. The remarkable similarity of Figures 1 and 4 provides convincing evidence for E_s type propagation observed by the oblique backscatter radar. The diurnal variation of vertical E_s occurrence at Ottawa (Figure 4) shows the same pattern as that derived from the oblique E_s propagation (Figure 1). It should be pointed out that Figure 4 represents data taken on all days at Ottawa without discriminating between quiet and disturbed days. However a separate study of the Ottawa E_s data indicated that magnetically disturbed periods showed less E_s activity, a fact that had been known earlier and has also been confirmed recently (Whitehead, 1970; Closs, 1971). Hence, Figure 3 generally represents quiet conditions. The exceptionally good statistical agreement between Figures 1 and 4 shows that during periods of quiet magnetic conditions absorption of the oblique rays in the D layer is not strong enough to cut off E_s propagation.

To prove that the statistical agreement referred to above, is also borne out on a one-to-one basis, the occurrence of E_s propagation was correlated with the presence of E_s in the vertical ionosonde data from Ottawa on an hourly basis for a particular month, namely June, 1961. The results show that if $fE_s \geq 4$ MHz at Ottawa, then the E_s propagation is observed 80 percent of that time. Considering that the observations were made only once every hour at Ottawa and the oblique sounder was operating continuously, this is a remarkably good correlation.

4.1. Correlation of FAE(E) and E_s Propagation.

The total occurrence statistics of FAE(E) during quiet magnetic periods over the years 1961-65, presented earlier in Report 1, are reproduced in Figure 5 for comparison with the E_s propagation occurrence, particularly from the NW quadrant. It

should be noted that the time scale is different in Figures 1 and 5. Keeping this in mind, we find that the definite summer evening maximum in FAE(E) is correlated extremely well with the evening maximum of both E_s propagation and fE_s at Ottawa. The other diurnal peak in E_s during the pre-noon hours has no accompanying FAE(E) activity at all. We shall attempt to reconcile these two points in the Discussion. The high association of E_s with FAE(E) during evening hours is further shown in Figure 6, which represents the percent occurrence of E_s associated FAE(E) from the NW for the five years of observation during quiet magnetic periods. During 2000 to 0300 hours E_s propagation is accompanied almost 50 percent of the time by FAE(E).

The occurrence of FAE(E) during magnetically disturbed periods (K_{FR} 4-9) is statistically insignificant for presentation in the form of contour diagrams as in Figure 5. Instead, this occurrence is presented in the form of average seasonal histograms over the five years of observation, as in Figure 7. The average seasonal behavior for very quiet (K_{FR} 0,1) and moderate conditions (K_{FR} 2,3) is also shown for comparison. These seasonal groupings are somewhat different from those presented in Report 1 and are found to be more meaningful in terms of occurrence statistics of E_s . The predominant summer nighttime maximum, weak secondary maximum in winter, and very low occurrence in the equinoctial months is apparent during both the very quiet and the moderately disturbed magnetic periods. The occurrence pattern of FAE(E) changes drastically when the magnetic field is severely disturbed. During this time, virtually all seasonal differences are wiped out and considerable FAE(E) activity is seen during the daytime. Thus there seems to be a threshold effect for the effects of magnetic disturbances on the formation of field aligned irregularities at E-layer heights. We shall comment on this point further in the Discussion.

5. F-LAYER PROPAGATION

The F-layer ground backscatter echoes or 1F echoes form a large fraction of the total data recorded. The echoes obtained at southern azimuths were stronger and more numerous. However, as pointed out earlier, we shall restrict ourselves to echoes obtained from the north. The greater majority of these was obtained at delays of 16-18 msec which corresponds to ground scattering distances of 2400-2700 km. The percentage occurrence contours of this type of echo during magnetically quiet periods are presented in Figures 8 and 9 for the NW and NE respectively. Though the occurrence of ground scatter is appreciably greater in the NE, both diagrams show a very marked solar cycle dependence. Another significant factor in both is the absence of daytime ground backscatter during the summer months - the backscatter appears much later in the day during the afternoon hours in the NE and even later around 1800 hours, in the NW.

5.1. Effect of E_s on F-layer propagation

As stated in the Introduction, it was our object to investigate the effects of blanketing, if any, caused by the intense sporadic-E clouds present so consistently during the summer on F-layer backscatter. A quick comparison of Figures 4 and 8 seems to indicate that absence of daytime ground backscatter during the summer may be caused by the presence of E_s . However, a closer look shows that the evening occurrence of F-layer propagation during this season coincides almost exactly with the evening maximum of E_s occurrence. Thus the daytime absence of F-layer echoes cannot be attributed to the presence of E_s , and we have to look for changes in the F-region parameters themselves for an explanation. It is our conclusion, therefore, that E_s at sub-auroral latitudes does not cause blanketing effects on the 1F mode of propagation. Bates (1969) came to a similar conclusion regarding the 1F mode signal after examining simultaneous records of HF backscatter

at College and the Thule-to-College forward oblique propagation in the auroral zone. In the absence of any amplitude records, we could not determine whether the presence of E_s causes any fall-off in the echo intensity. However, since F-layer propagation with this low power system could exist simultaneously with the rather intense evening E_s maximum, our tentative conclusion is that it does not cause any appreciable loss of intensity.

5.2. Effect of direct ionospheric scatter on F-layer propagation.

We have seen in Section 4 of this Report that direct ionospheric scatter from the E region, FAE(E), is highly correlated with the presence of E_s propagation. This lends support to the theory of weak scatter, developed by Booker (1956), in which he postulated that only a small fraction of the incident energy is scattered back towards the radar by the field aligned irregularities which provide discontinuities in the dielectric constant. Again, in the previous section we have seen that the E_s clouds themselves are of the non-blanketing type. At these latitudes sufficient refraction must be present in the underlying layers to produce aspect sensitivity at F-layer heights. Looking north from the Plum Island radar, the magnetic field direction is so nearly vertical that aspect sensitivity requirements are met close to the reflection level, i.e., when the ray travels horizontally. Thus the existence of the 1F mode becomes an almost necessary condition for the occurrence of direct scatter from the F layer. If the direct scatter and 1F mode echoes occur simultaneously, we can assume that the direct scatter is rather weak. The occurrence of direct scatter is further dependent on another crucial factor, namely, the presence of field aligned irregularities at the latitude of interest at that particular local time.

To study the simultaneous occurrence of the 1F mode of propagation and FAE(F) we constructed Figure 10. This diagram shows the diurnal variation of the occurrence of the F-layer

echo over 5 years of observation as well as the percentage of the time that FAE(F) accompanied the F-layer echo. Figure 10 shows that the hours of greatest F-layer echo occurrence are accompanied by a negligible percentage of FAE(F), whereas the evening hours with rapidly tapering 1F echo occurrence are those which are accompanied by FAE(F) for 25 to 50 percent of the time. This diurnal variation during quiet times can be immediately explained in terms of the irregularity region obtained from scintillation measurements as shown in Figure 11 (Aarons and Allen, 1971) which shows that the low latitude scintillation boundary approaches 60° invariant at 1700 hours local time. This is precisely the time beyond which an appreciable FAE(F) activity is observed. Thus if irregularities are present, then it is possible to have simultaneous FAE(F) and 1F echoes.

During disturbed times the equatorward scintillation boundary is found to move southwards. Thus it is quite possible from boundary concepts to expect irregularities and hence FAE(F) activity. Figure 12 shows the diurnal variation of hours of 1F echo as well as the percentage of the time that this 1F echo was accompanied by FAE(F). That the FAE(F) is present simultaneously for 30 percent of the time the 1F echo is present proves that direct scatter from the F-region irregularities is weak in nature and the limiting factor in Figure 10 was the absence of irregularities. Comparing Figures 10 and 12 and noting that the number of $K_{F1}4-9$ samples is only 10% of the number of $K_{F1}0-3$ samples, we find a tremendous increase of FAE(F) activity during magnetic storms in the hours when F-layer propagation is simultaneously present.

For the sake of completeness, as well as a one-to-one comparison with Figure 8, we have reproduced from Report 1 the FAE(F) occurrence contours obtained over the 5 years of observation in the NW quadrant during quiet times in Figure 13. The sunset peak of occurrence and solar cycle dependence is very clearly displayed. The diurnal, seasonal, and magnetic effects

are also very clearly depicted in Figure 14. It is interesting to note the increase of echo occurrence with increasing magnetic index in each season excepting the summer. The explanation for this is the generally observed fact that summer magnetic storms at midlatitudes are usually accompanied by a decrease of f_oF2 , whereas the opposite is the case in winter (Matsushita, 1959; Maeda and Sato, 1959). Although Figure 14 generally shows increase of FAE(F) with each range of magnetic index, an earlier study (Report 1) showed that FAE(F) increased monotonically with K_{F_r} until $K_{F_r}=4$ and then decreased thereafter, attaining complete cut off for $K_{F_r} \geq 7$. The complete cut off for $K_{F_r} \geq 7$ shows that severe magnetic storms in any season are accompanied by a decrease in f_oF2 at these latitudes as is the case at high latitude stations for even moderate storms. In contrast FAE(E) showed uniformly high activity for K_{F_r} ranging from 6 to 9. These results are reproduced in Figure 15.

It is our conclusion that direct ionospheric scatter does not affect F-layer propagation. Rather, F-layer propagation is often required to produce FAE(F) at locations where direct orthogonality between the ray-path from the radar and the geomagnetic field is not achieved for straight line propagation.

5.3. Effect of varying F-region parameters on 1F propagation.

It was pointed out previously that the disappearance of F-layer propagated echoes during the summer, as shown in Figures 8 and 9, was probably caused by the seasonal variation of the F-region parameters and not due to blanketing effects of E_s ionization. The two most important parameters affecting F-layer propagation are its critical frequency f_oF2 , and the true height of maximum ionization h_mF2 . However, the true height analysis of ionograms is not carried out on a routine basis and hence the maximum usable frequency factor of the F2 layer for a distance of 3000 km, $M(3000)F2$, was used to obtain relative variation of the true height between one time

and another. It has been shown by Shimazaki (1955) that for most electron density profiles the height of the maximum electron density is approximated by $h_p F2 = 1490/M(3000)F2 - 176$. Thus the variation of $M(3000)F2$ indicates the trend in the variation of $h_p F2$ - the lower values of $M(3000)F2$ corresponding to higher values of $h_p F2$ and vice-versa.

The ionosonde stations to the NW and NE of Plum Island are Winnipeg (49.9°N, 97.4°W) and St. John's (47.6°N, 52.7°W), respectively, and their data are considered to represent ionospheric F2-layer conditions in these two directions. Hence contours of the monthly median $f_o F2$ and $h_p F2$, calculated from the $M(3000)F2$ factor by Shimazaki's relation, were drawn for both stations using DRTE(Ottawa) Canadian data books. These are shown in Figures 16 through 19. Systematic differences are found between the $f_o F2$ contours of the two quadrants - the median critical frequency to the NE always being higher than that of the NW at a particular hour, usually by at least 0.5 MHz. This higher critical frequency is responsible for the higher percentage of the time that F-layer propagation is present to the NE. Looking at the $h_p F2$ contours we find that the summer daytime values are the highest of any season in addition to being accompanied by the lowest values of $f_o F2$. This particular combination of high $h_p F2$ and low $f_o F2$ is responsible for the disappearance of F-layer propagation in the daytime. However, it reappears in the evening when the $f_o F2$ is higher and the $h_p F2$ is lower. The solar cycle variation is manifested by a decrease of $h_p F2$ from 1961 to 1964. However, this favorable trend is more than compensated for by an accelerated decrease of $f_o F2$ with the declining solar cycle, so that we observe a general decrease of F-layer propagation. A separate empirical study is underway to determine particular combinations of $f_o F2$ and $h_p F2$ which will yield the observed percentage of F-layer propagation.

We thus conclude that the F-region parameters themselves are crucial in determining the extent of F-layer propagation.

We have observed that in a particular quadrant the F-layer propagation varies with time of day, season, and sunspot number. This is largely dictated by the variable shape of the f_oF2 vs. time curves as a function of season. We find from Figure 16 that the winter f_oF2 vs. time curves show a single midday maximum which is greater than the f_oF2 at any other season. This is the seasonal anomaly. The summer and equinox months on the other hand show an evening peak which is usually greater than the midday value. This is generally referred to as the evening anomaly. Strobel and McElroy (1970) made computations for a latitude of 43°N under sunspot minimum conditions and found that most of the seasonal variations as well as the evening anomaly could be explained by altering the atmospheric composition, specifically that of O/O_2 , keeping the aggregate oxygen mass constant, at a base level of 120 km. Thus, contrary to general expectations, neutral winds are not the direct cause of the seasonal anomaly (Rishbeth, 1968).

Neutral winds, however, are largely responsible for the other noteworthy feature that has emerged from these observations, namely, the greatly enhanced F-layer propagation in the NE as compared with the NW. The two ionosonde stations chosen to represent conditions in these general directions are St. John's (NE) and Winnipeg (NW). These stations, though similar in latitude, differ in magnetic declination. St. John's has the rather large westerly declination of 27°W whereas Winnipeg has a declination of 10°E . The difference in F2-layer behavior at places of similar latitude but opposite declination has been discussed in a recent review on thermospheric winds by Rishbeth (1972) and also by Kohl et al (1969). These authors conclude that wind effects can account for the dependence of the diurnal F2-layer variations on declination, that had been suggested previously by Eyrfrig (1963). Thus we find that factors such as changes in atmospheric composition and neutral winds indirectly control F-layer propagation.

6. GENERAL DISCUSSION ON FORMATION AND OCCURRENCE OF FIELD ALIGNED IRREGULARITIES

6.1. FAE(E)

The statistical results of the occurrence of FAE(E) in this study extending over half a solar cycle seem to agree well with Forsyth's (1969) recent paper on the occurrence of radio aurora over a full solar cycle. He finds a consistent summer maximum throughout the solar cycle. However, the diurnal variation of radio aurora shows a daytime maximum as opposed to the nighttime maximum that is observed at Plum Island. It should be noted that Forsyth's paper was based on forward scatter measurements made at 40 MHz between a transmitter located at Greenwood and receiver located at Ottawa on an east-west line. As indicated earlier, the oblique backscatter observations reported in this study sound the ionosphere over Ottawa for E-region heights. Thus the two sets of measurements refer to ionospheres at almost the same invariant latitude, but located possibly a few hundred km apart in the east-west direction. Referring to the earlier paper by Collins and Forsyth (1959), it becomes evident that the daytime summer maximum reported by Forsyth must be caused by the S-type scatter (classified as A_4 by IAGA, 1968) which is weakly aspect-sensitive and is not correlated with magnetic disturbances. This type of irregularity when existing at the zenith at Ottawa is reported as E_s and gives rise to the E_s -type propagation that is so consistently observed during the summer daytime under quiet conditions. Forsyth also makes the comment that even if the daytime occurrences are eliminated, the summer maximum still remains - a fact which is adequately borne out by our observations.

The current thinking (Unwin and Knox, 1971) is to explain radio aurora, i.e., aspect-sensitive high latitude disturbances strongly related to magnetic storms, in terms of either Farley's (1963) 'ion-acoustic instability' or the 'drift-gradient instability' developed by Simon (1963) and Hosh (1963). Unwin and Knox (1971) further show that the B1 or diffuse type of

radio aurora is probably due to the ion-acoustic instability, whereas the B2 and B3 (discrete) types are probably due to the drift-gradient instability. These authors also point out that the condition for the onset of the latter type of instability is inversely proportional to the square of the wavelength thus making an HF system very sensitive for its detection. An order of magnitude estimate shows that an electric field of 1 mv/m may be adequate for causing this kind of instability at HF and this value is well within the range that can be accounted for by normal ionospheric winds. Thus the drift gradient instability could be one of the possible causes for the formation of FAE(E) during magnetically quiet and moderately disturbed times. The ion-acoustic instability, on the other hand, requires a threshold electric field of the order of 30 mv/m even at HF. It may be reasonable to expect fields of this order at E-region heights for quite disturbed conditions ($K_{pR} > 4$) at approximately 60° invariant latitude. Thus the FAE(E) observed during strong disturbances could very well have been caused by this instability (Gadsden, 1967; Moorcroft, 1972).

Goodwin (1965) found Booker's theory (1965) of scattering to be adequate for the explanation of his 16 MHz data and the same argument may be valid for this 19 MHz data obtained during quiet times in the presence of non-auroral E_s . This non-auroral E_s provides as high a background ionization as do irregularities occurring in the aurora. These irregularities in electron density which are elongated along the magnetic field are supposed to be randomly distributed, and are caused by atmospheric turbulence. Recent measurements of nighttime and twilight wind profiles from chemical trails have shown that turbulence once initiated maintains itself for 30 percent of the time at altitudes below 110 km (Rosenburg and Zimmerman, 1972). Booker assumed the blobs of ionization to be gaussoid in form. Later measurements (Chesnut et al, 1968) have shown that the gaussoid model is not a good one for representing radio aurora, and it is Bates' view (1969) that Booker's scattering theory is general and does indeed apply in most cases; rather it is the gaussoid model that does not apply.

6.2. FAE(F)

The percentage occurrence contours of FAE(F) show that during quiet periods they are primarily a sunset phenomenon. During disturbed periods, however, they are found to occur more frequently in the daytime, in addition to their sunset occurrence. It is to be emphasized that their diurnal peak of occurrence should be interpreted in terms of their aspect sensitivity requirements which in this case is dependent on refraction due to underlying ionization. If the probing HF radar had been at a somewhat lower geomagnetic latitude, such as that at Brisbane, the diurnal peak would have occurred closer to midnight when the irregularities are found to be most predominant from scintillation measurements (Aarons et al, 1969). Such were indeed the findings with a 16 MHz radar situated at Brisbane (Matthew, 1961). This led Bates (1969) to suggest that statistical studies of any given type of echo (e.g., E-scatter or F-scatter) are not too meaningful because the same scattering region gives different answers when viewed from different locations. However, it is quite correct to suggest that near-sunset conditions are conducive to the formation of field aligned irregularities in the mid-latitude ionosphere, whereas during the daytime, conditions are relatively unfavorable. Bates (1971) has shown that slant-F echoes were seen on a one-to-one basis whenever the vertical incidence F-layer traces were spread at College. At that station, which is well within the auroral oval, these slant-F echoes were present much of the time between roughly 1600 and 0600 LT. Slant-F echoes were, however, observed only occasionally at Palo Alto, California during 1964. Plum Island, being at an intermediate latitude, should show intermediate occurrence. Bates comes to the conclusion that the slant-F echoes are produced by highly aspect-sensitive backscatter from field aligned irregularities in the F layer. It is thus quite reasonable to assume that the oblique backscatter sounder will show

F_AE(F) activity when spread-F conditions are reported by relevant ionosondes. Positive correlations between spread-F and F_AE(F) were reported by various authors (Herman, 1966 and various authors quoted therein). However most authors also report the presence of spread-F without corresponding F_AE(F) activity, thus showing that the vertical ionosonde is a more sensitive detector of irregularities than a backscatter sounder (Au, 1970). Bates (1971) and Au(1970) found sufficiently good agreement between the existence of irregularities producing F_AE(F) and the scintillation boundary (Aarons, et al, 1969) to invoke the same mechanism for the formation of the irregularities. Very recently Kelley and Mozer (1971) have found evidence of turbulent electrostatic fields whose daytime and nighttime equatorward boundary agree extremely well with that determined by Aarons and Allen (1971). Kelley and Mozer were making in situ low frequency vector electric field measurements from orbiting satellites at a height of 400 km. It is interesting to note that these signals showed significant peaks when the spacecraft was in the statistical auroral oval as defined by Feldstein (1966). Kelley and Mozer quote a peak intensity at 12 Hertz of 1 mv/m · hertz^{1/2}. However, without knowing the spectral characteristics over the entire bandwidth it is difficult to compare this value with other quoted dc field measurements.

The existence of electrostatic fields and plasma density gradients in the ionosphere are known to give rise to a unique type of instability known alternatively as 'cross-field instability' or 'drift-gradient instability' which can result in the growth of ionization density irregularities that are aligned along the earth's magnetic field. It will be recalled that this type of instability has been invoked for the explanation of the B2 and B3 types of radio aurora at E-layer heights (Unwin and Knox, 1971). Reid (1968) considered the formation of field aligned irregularities in the F-region due to this mechanism and Au(1970) later extended his calculations for a station at the dip pole. From these calculations, it is evident

that the dynamo region of the ionosphere is quite likely to be unstable in the presence of moderate electric fields to the growth of irregularities with scale sizes in the range from a few tens of meters to a few kilometers. Conduction of the small-scale electrostatic fields associated with this instability up the magnetic field lines can give rise to the growth of irregularities of corresponding scale sizes in the F-region. However, the theory is still on a rather tentative footing and no rigorous theory of formation of field aligned echoes seems to have yet been formulated.

6.3. Conclusions

While the physics of the origin of the irregularities are in the process of being developed, the morphology of the irregularity region is clear. Irregularities exist in the region hatched in Figure 11. With the acceptance of this model, the geometry of the probing radar becomes the all important factor with the propagation angle and the local ionospheric parameters forming the basis for the occurrence statistics. Knowledge of the diurnal pattern of the irregularity region, and the intensity within the irregularities across the auroral zone and the polar cap is being expanded by high latitude observations as well as by observations near the scintillation boundary. With statistics such as shown in this paper, it should be possible, given the morphology and the height and critical frequency of the F2 layer, to work out occurrence statistics for field aligned echoes in the F region.

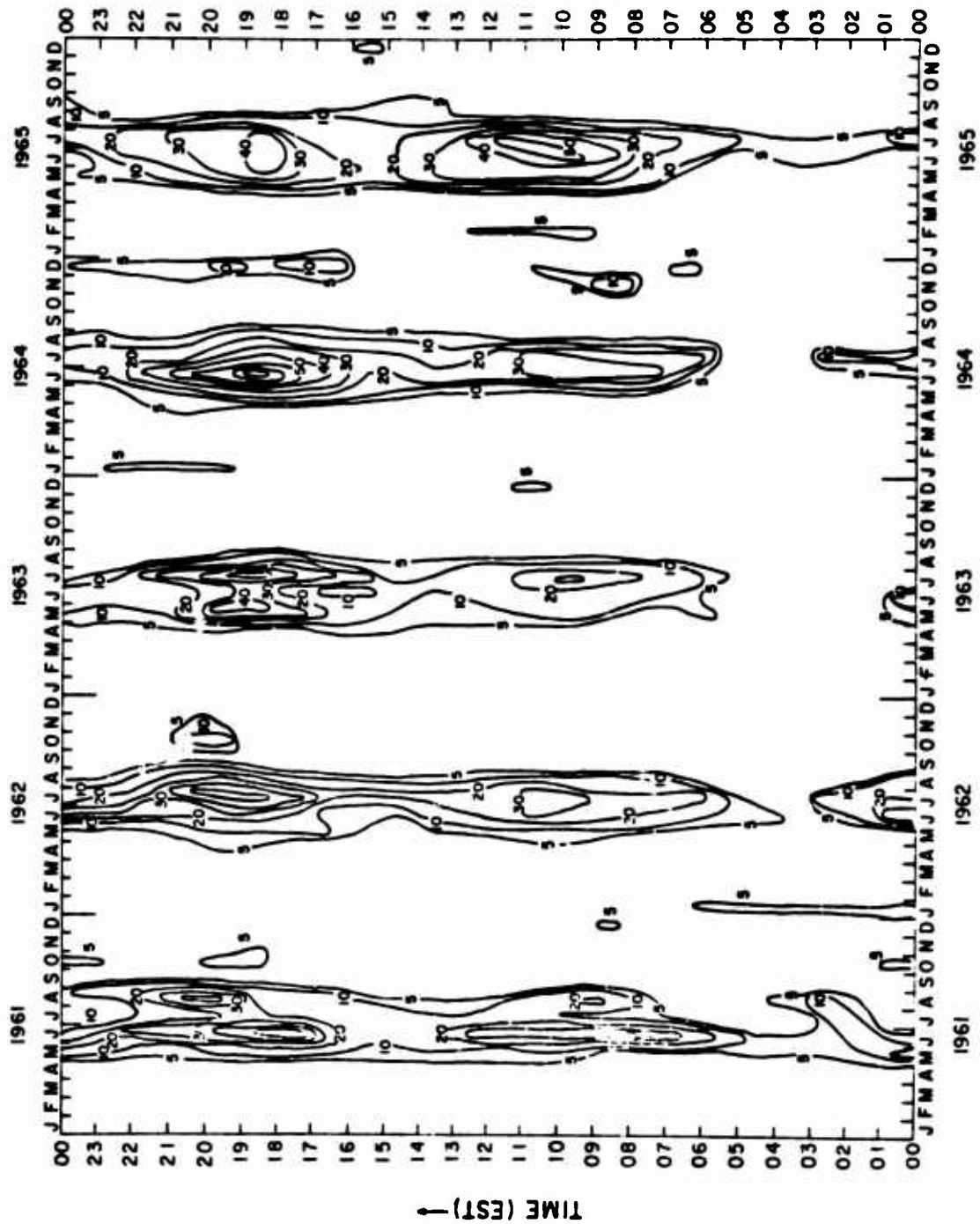


FIG. 1. PERCENTAGE OCCURRENCE CONTOURS OF E_s PROPAGATION IN THE NW QUADRANT FOR $K_{fr} 0-3$

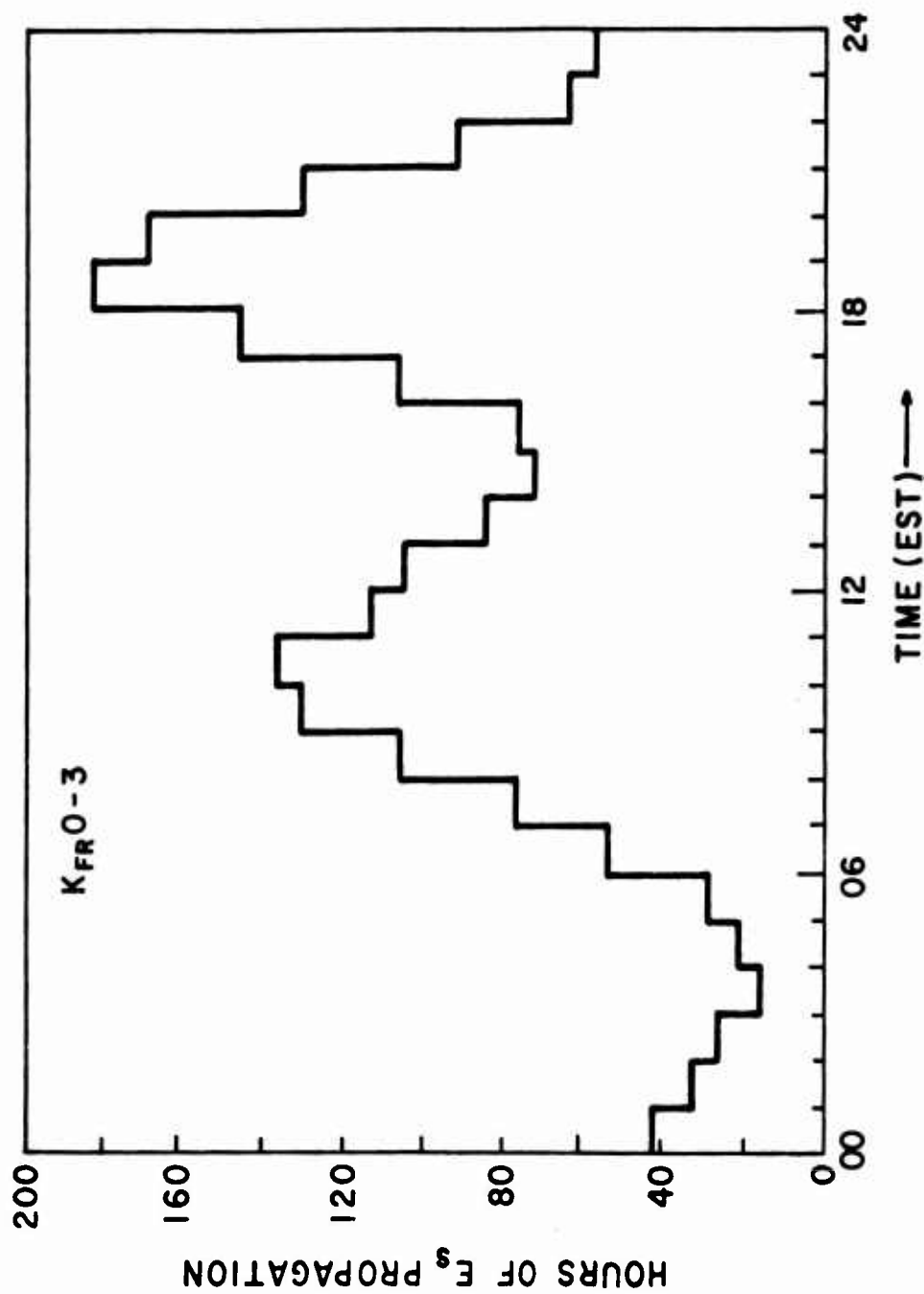


FIG. 3. AVERAGE DIURNAL VARIATION OF E_s PROPAGATION
IN THE NW QUADRANT FOR KFR 0-3, 1961-1965

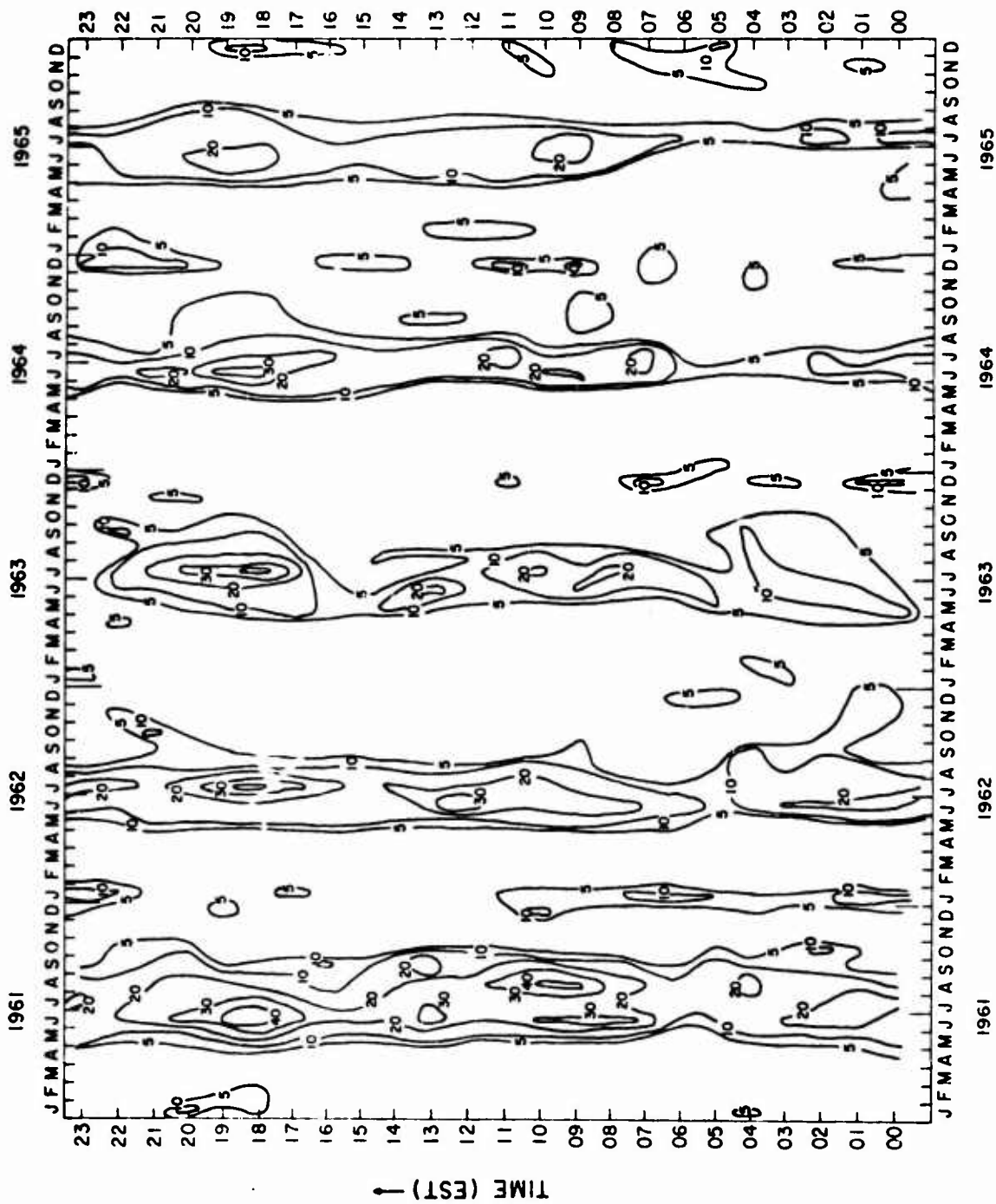


FIG. 4. PERCENTAGE OCCURRENCE CONTOURS OF $f_0 E_s \geq 5$ MHz FOR OTTAWA

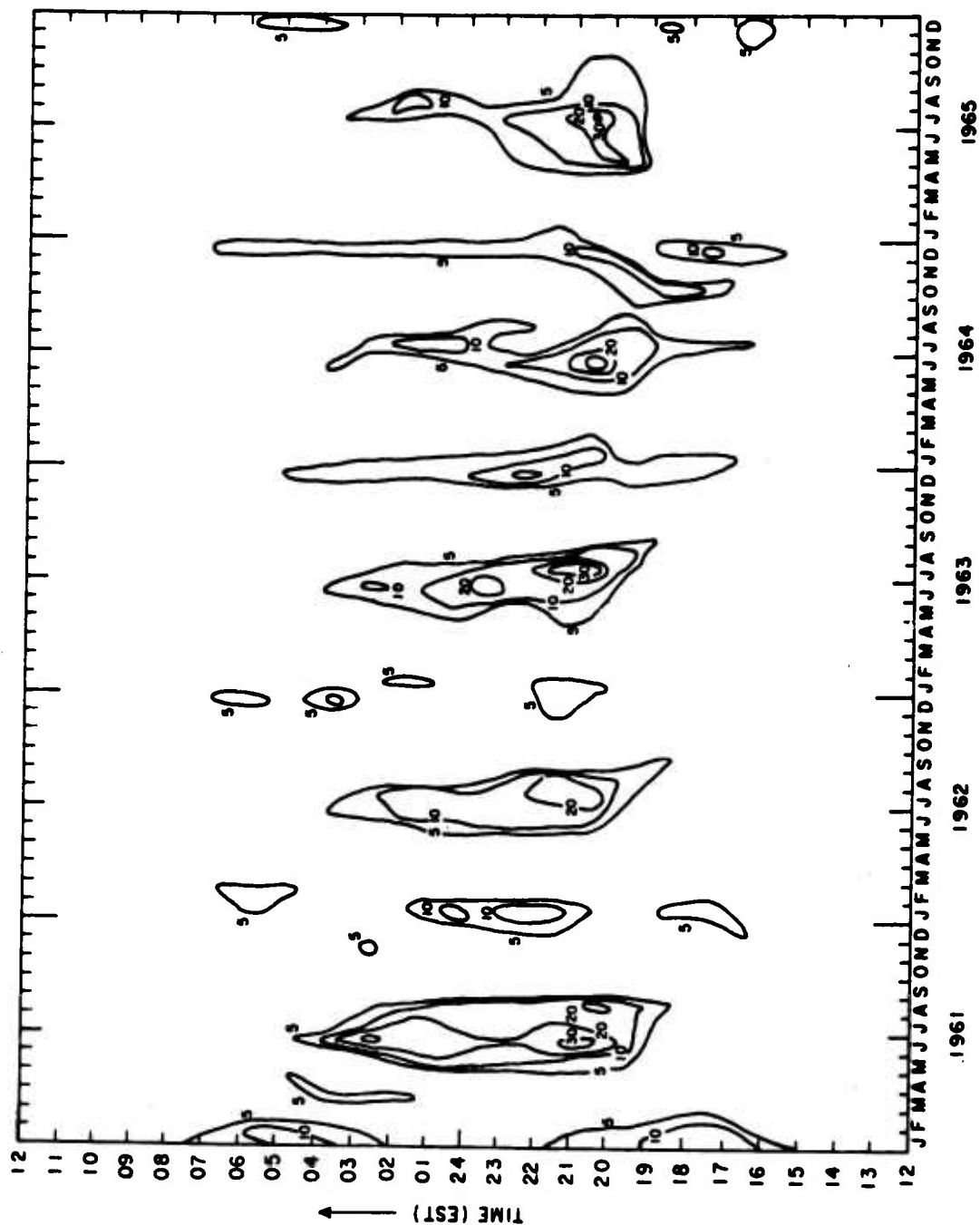


FIG. 5. PERCENTAGE OCCURRENCE CONTOURS OF FAE (E) FOR KFR 0-3

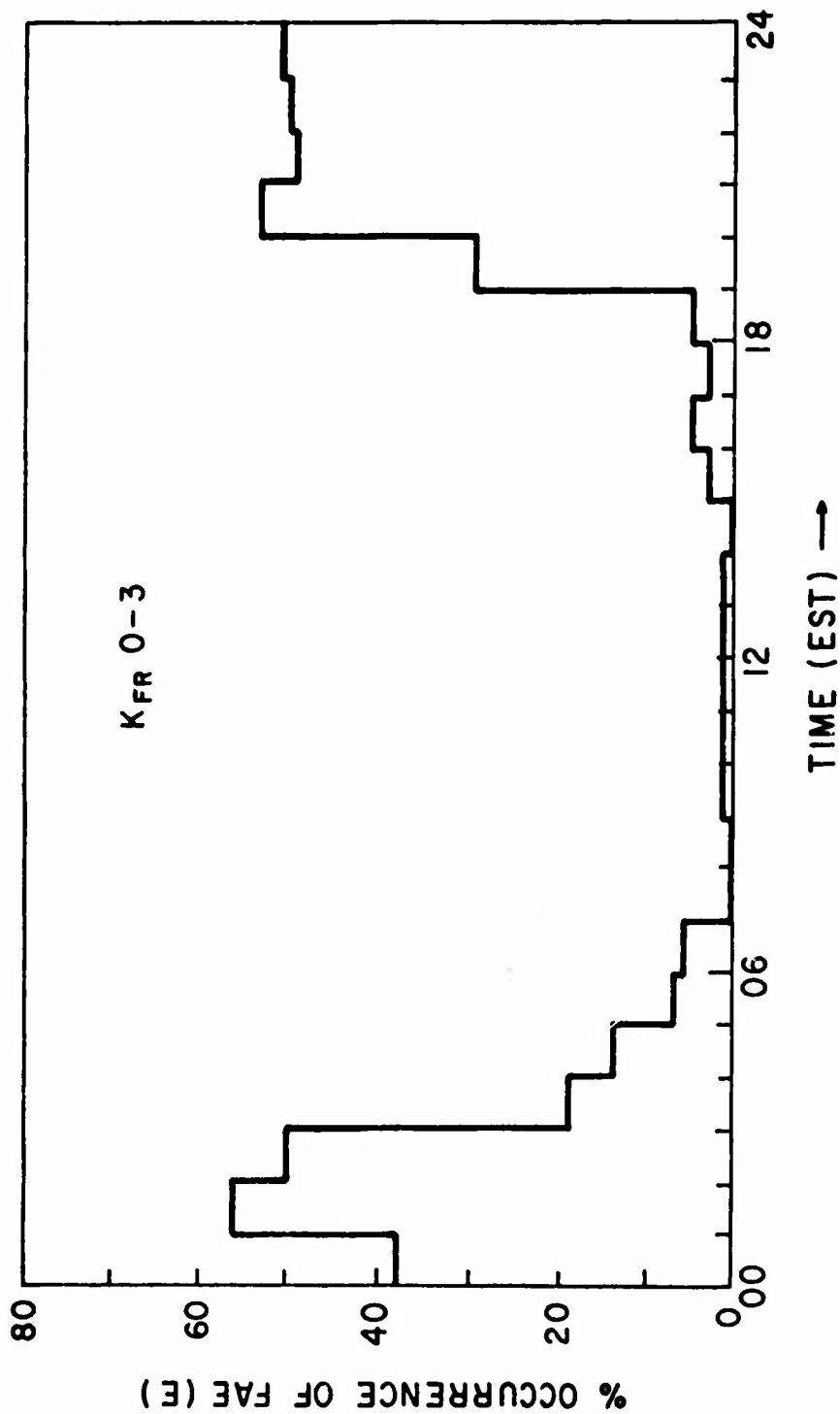


FIG. 6. AVERAGE DIURNAL VARIATION OF FAE(E) WHEN E_s PROPAGATION IS PRESENT FOR KFR 0-3, 1961 - 1965

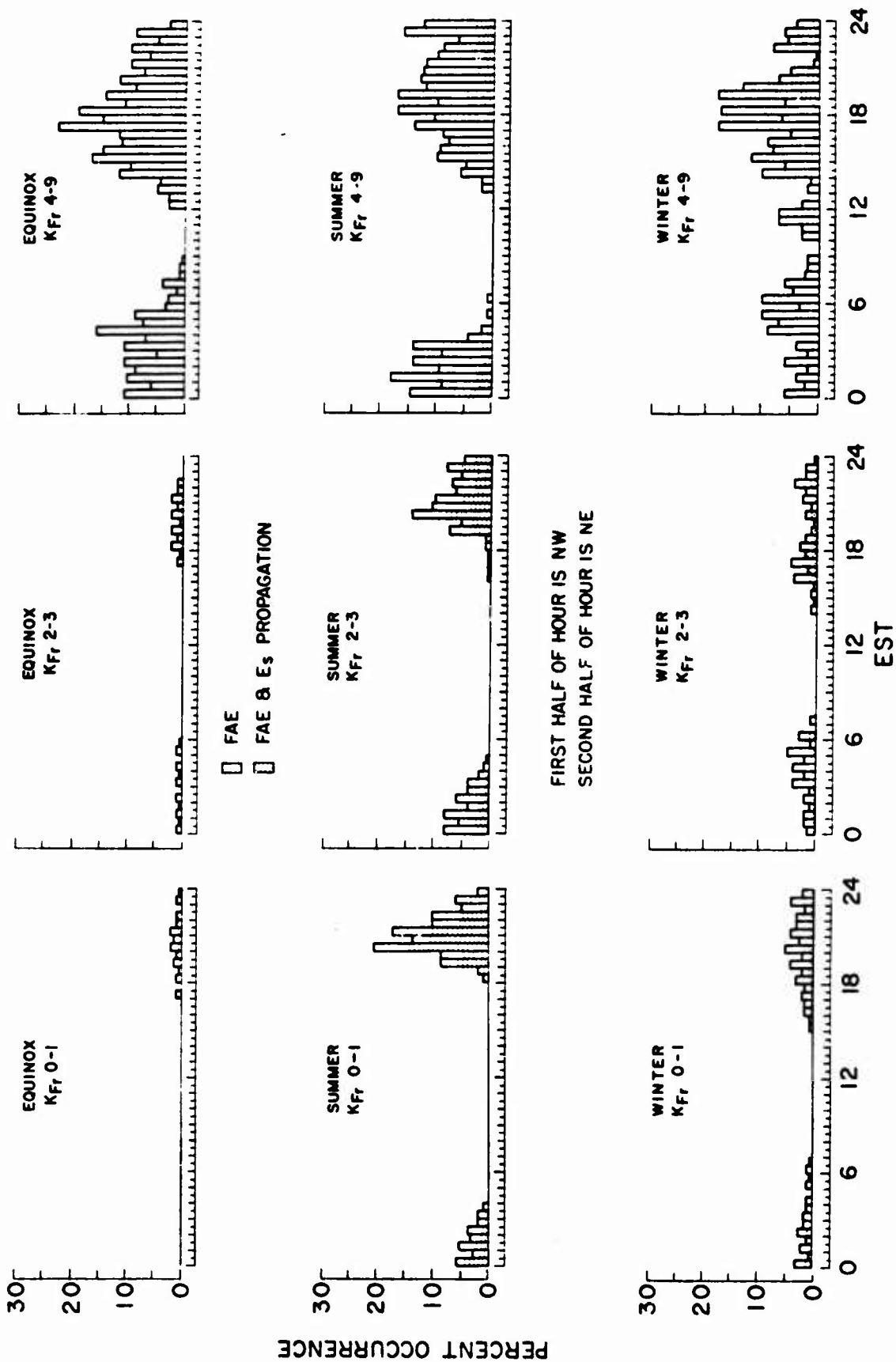


FIG. 7. AVERAGE SEASONAL VARIATION OF FAE (E) FOR VARIOUS RANGES OF KFr, 1961-65.

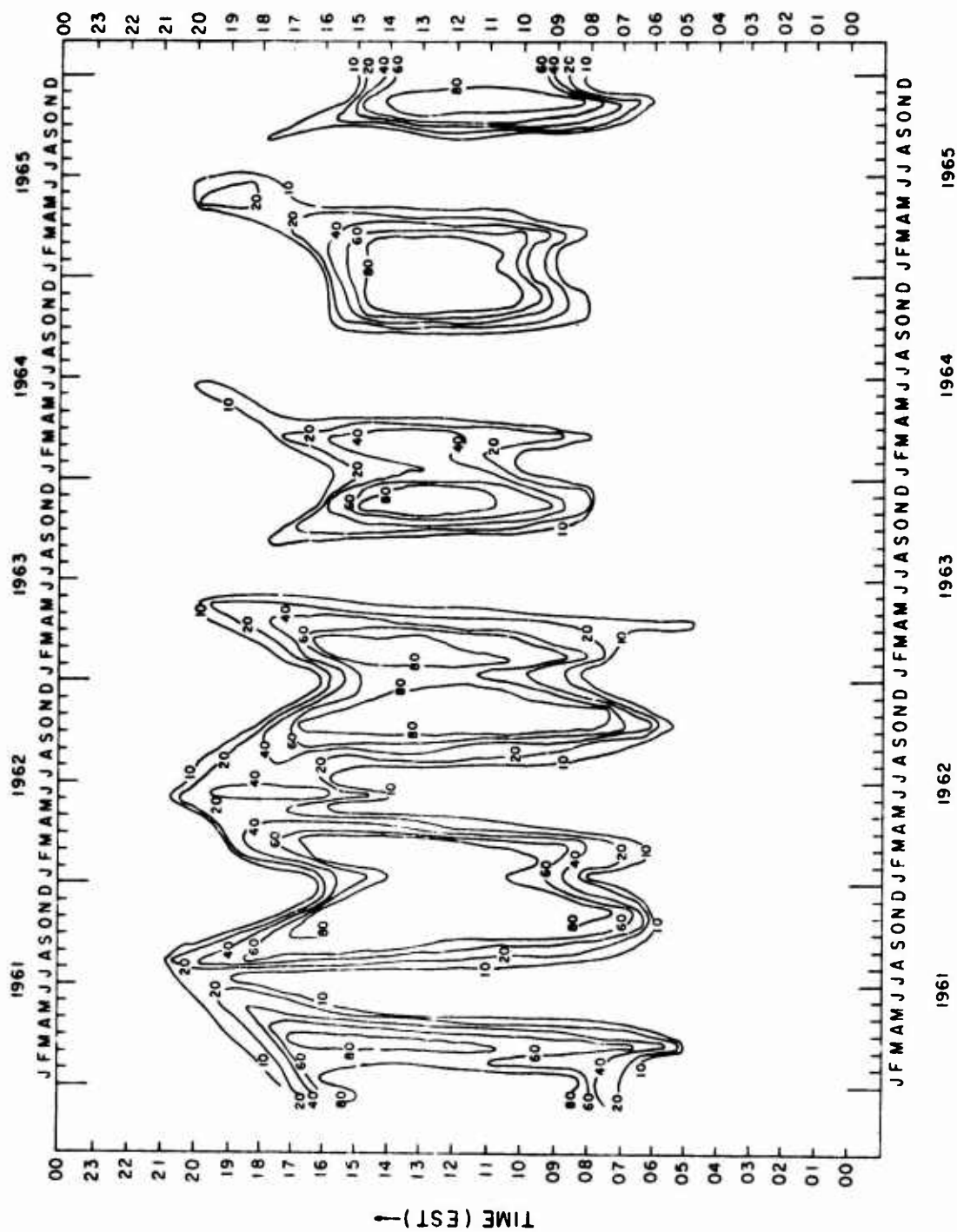


FIG. 8. PERCENTAGE OCCURRENCE CONTOURS OF IF ECHO IN THE NW QUADRANT FOR KFR 0 - 3

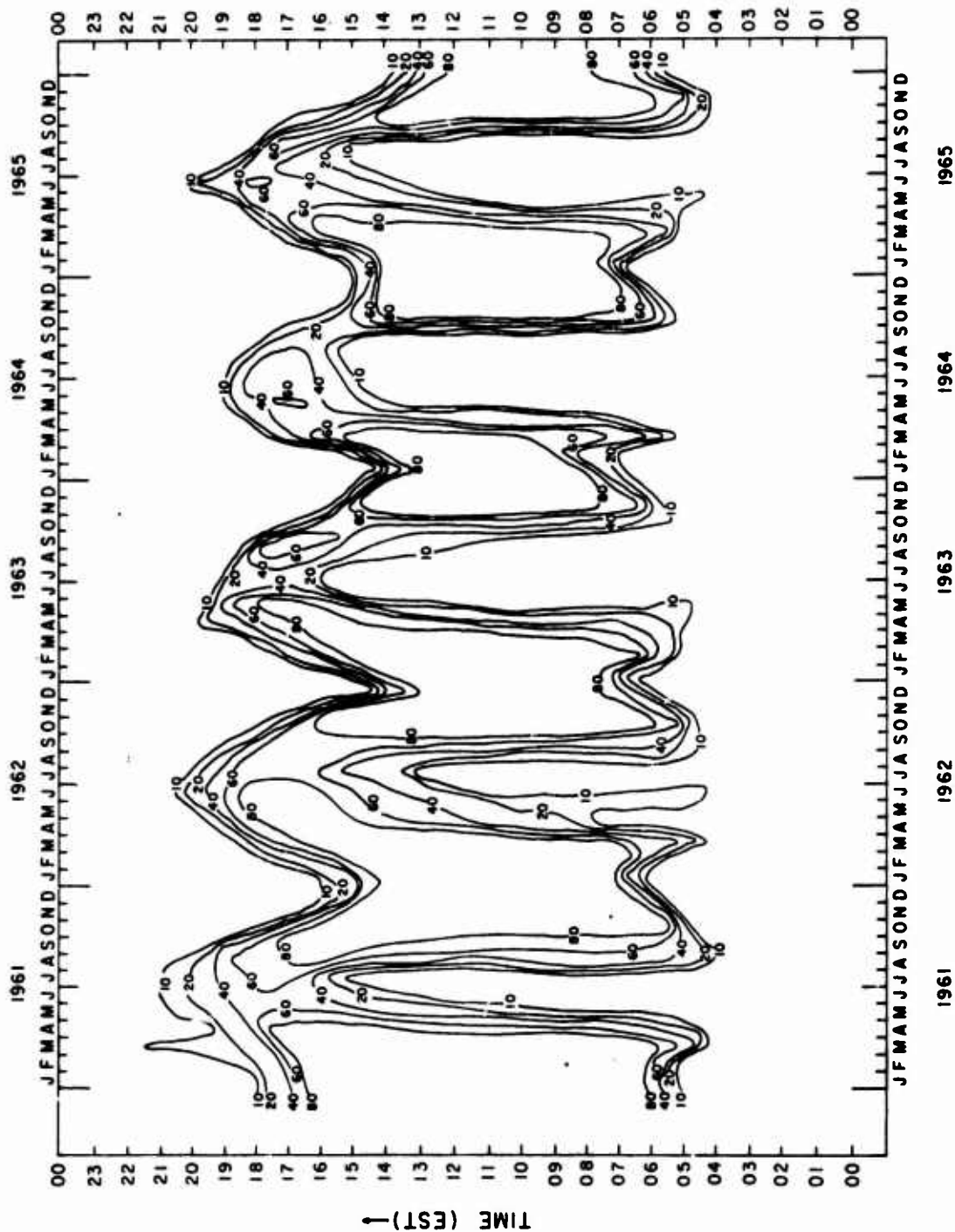


FIG. 9. PERCENTAGE OCCURRENCE CONTOURS OF 1F ECHO IN THE NE QUADRANT FOR KFR 0 - 3

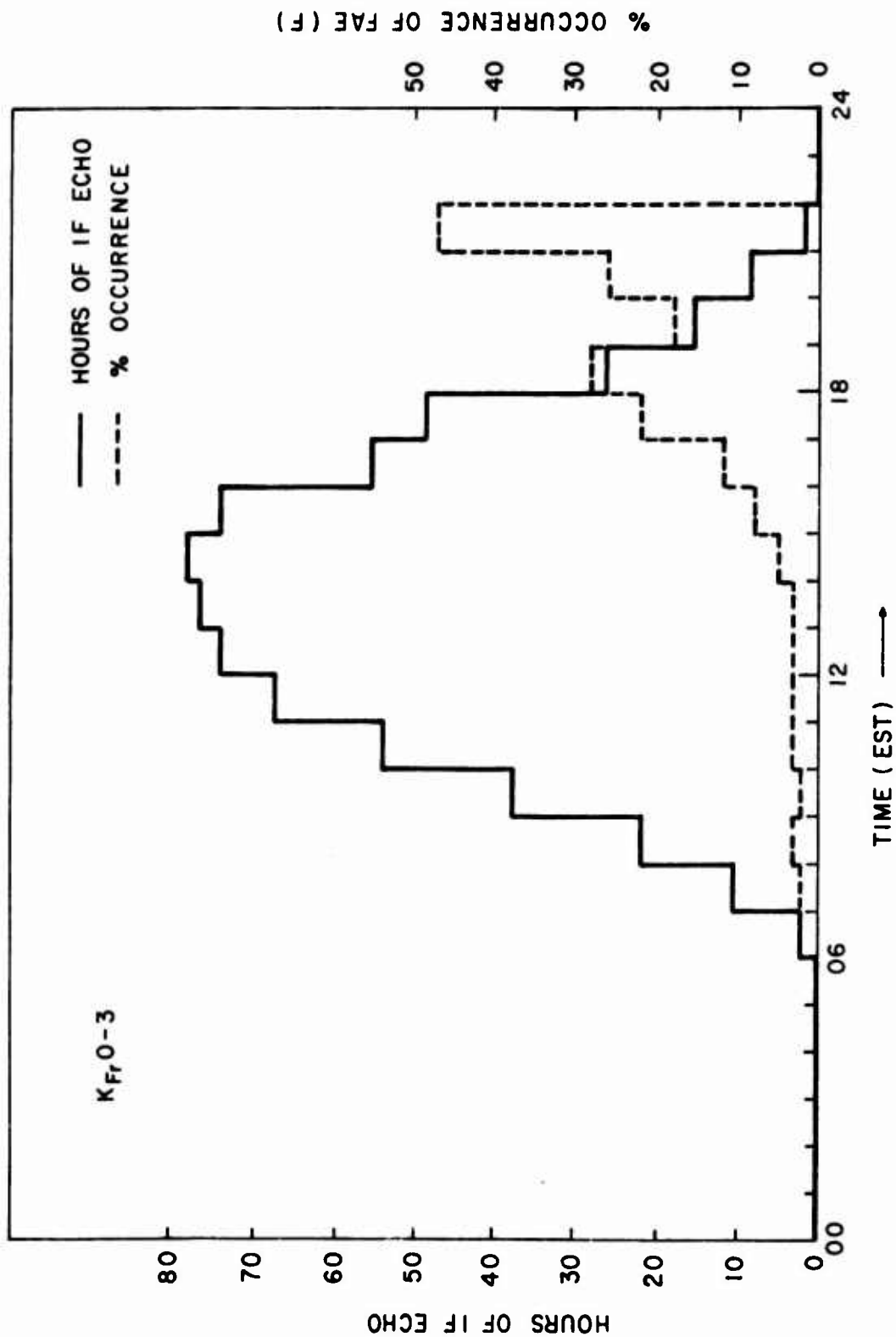


FIG. 10. AVERAGE DIURNAL VARIATION OF IF ECHO OCCURRENCE AND OF FAE (F) OCCURRENCE WHEN IF ECHO IS PRESENT FOR KFR 0-3, 1961 - 1965

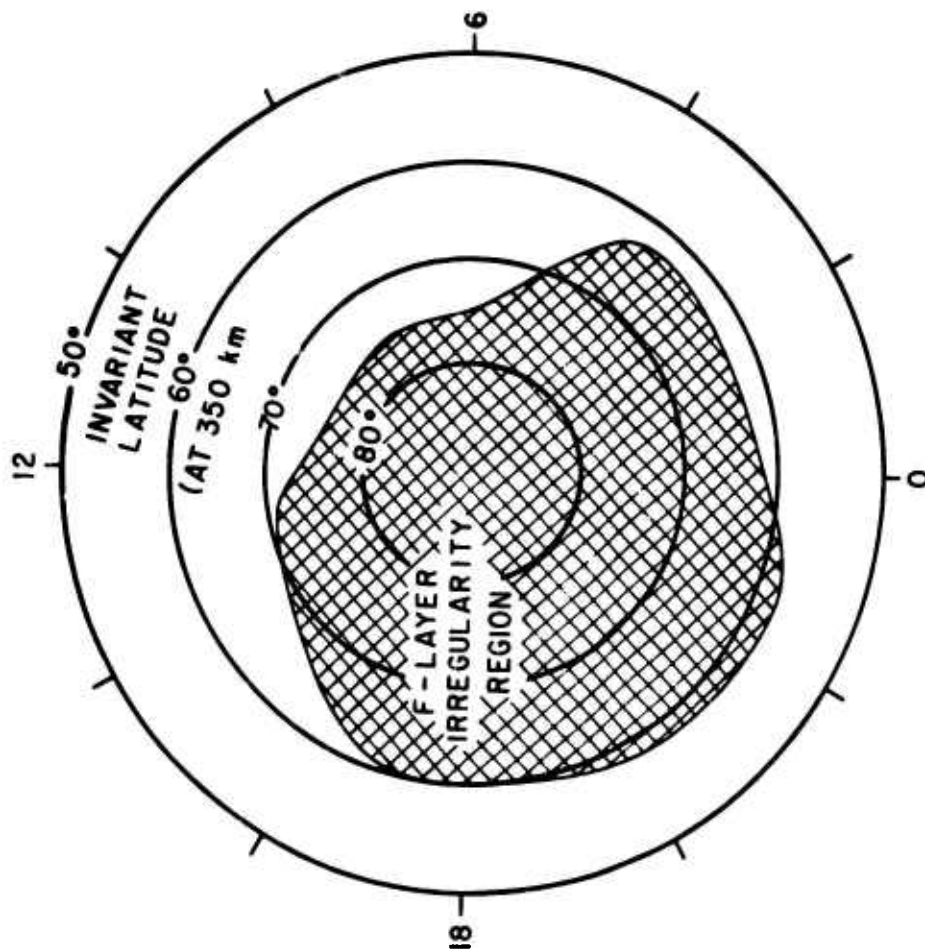


FIG. II. DIURNAL PATTERN OF THE EXTENT OF THE F-LAYER IRREGULARITY REGION
DURING QUIET MAGNETIC CONDITIONS (K_p 0-3)

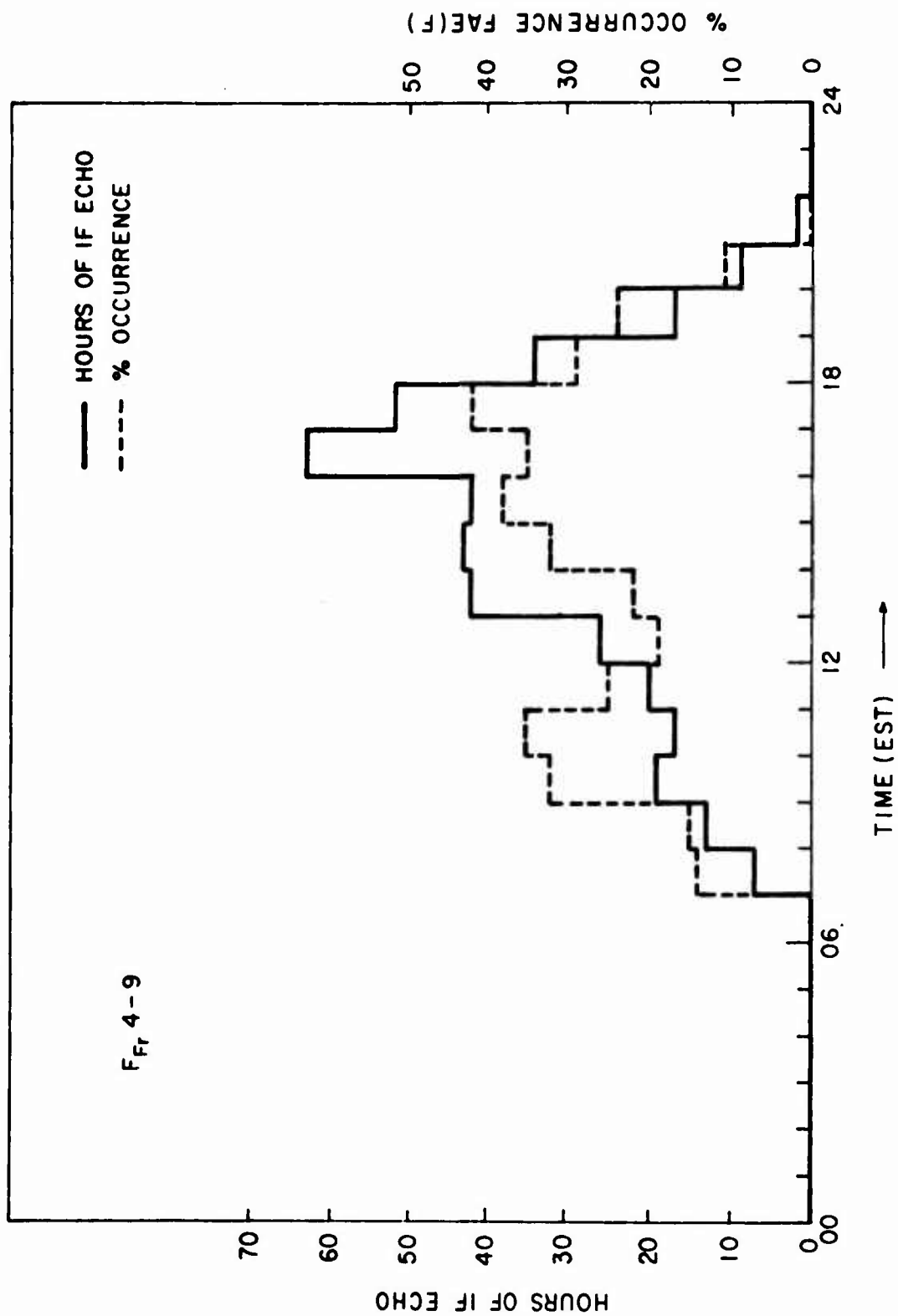


FIG. 12. AVERAGE DIURNAL VARIATION OF IF ECHO OCCURRENCE AND OF FAE(F) OCCURRENCE WHEN IF ECHO IS PRESENT FOR $K_{Fr} 4-9$, 1961-1965

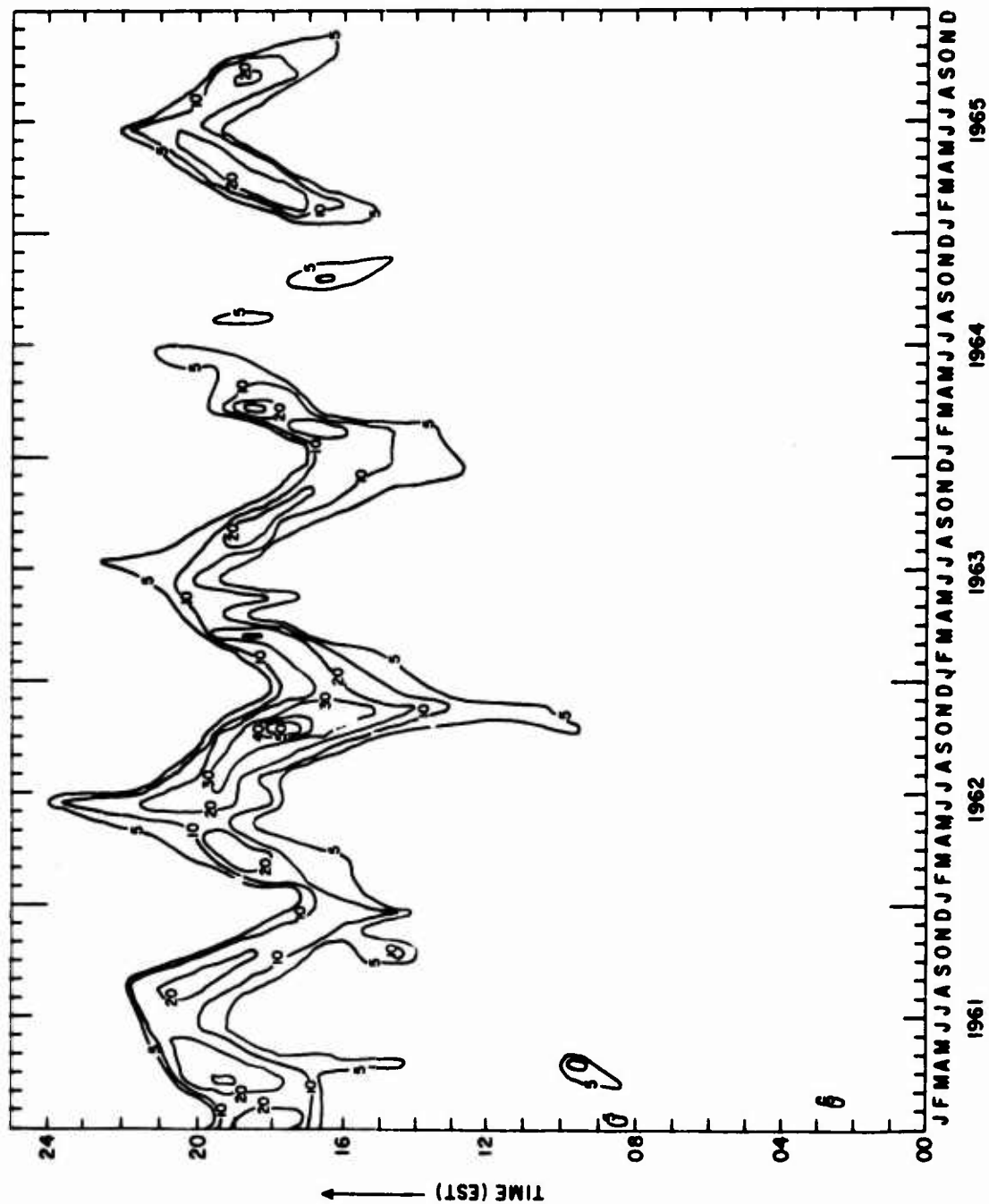


FIG. 13. PERCENTAGE OCCURRENCE CONTOURS OF FAE(F) FOR KFR 0-3

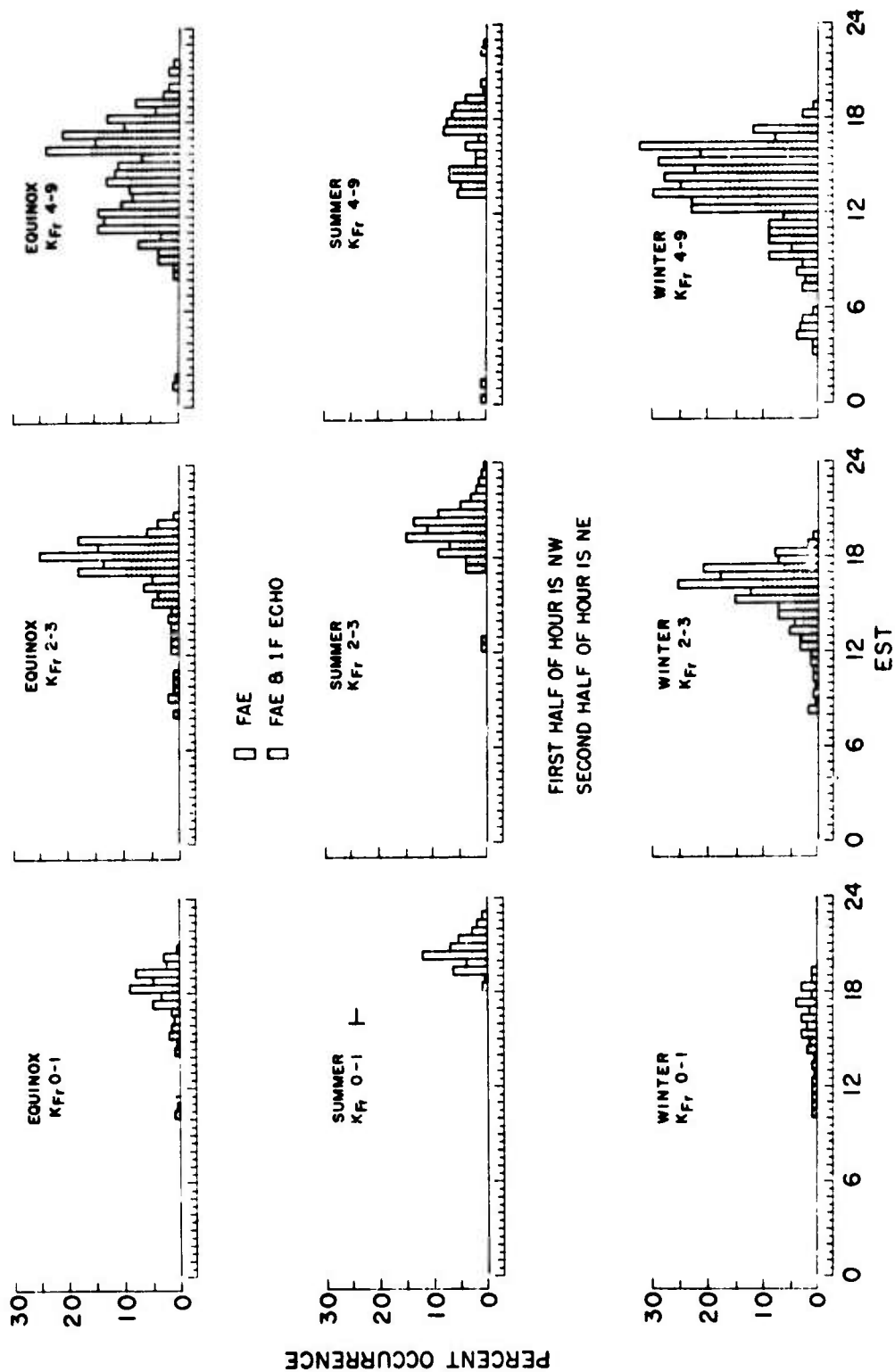


FIG. 14. AVERAGE SEASONAL VARIATION OF FAE (F) FOR VARIOUS RANGES OF KFr, 1961 - 65.

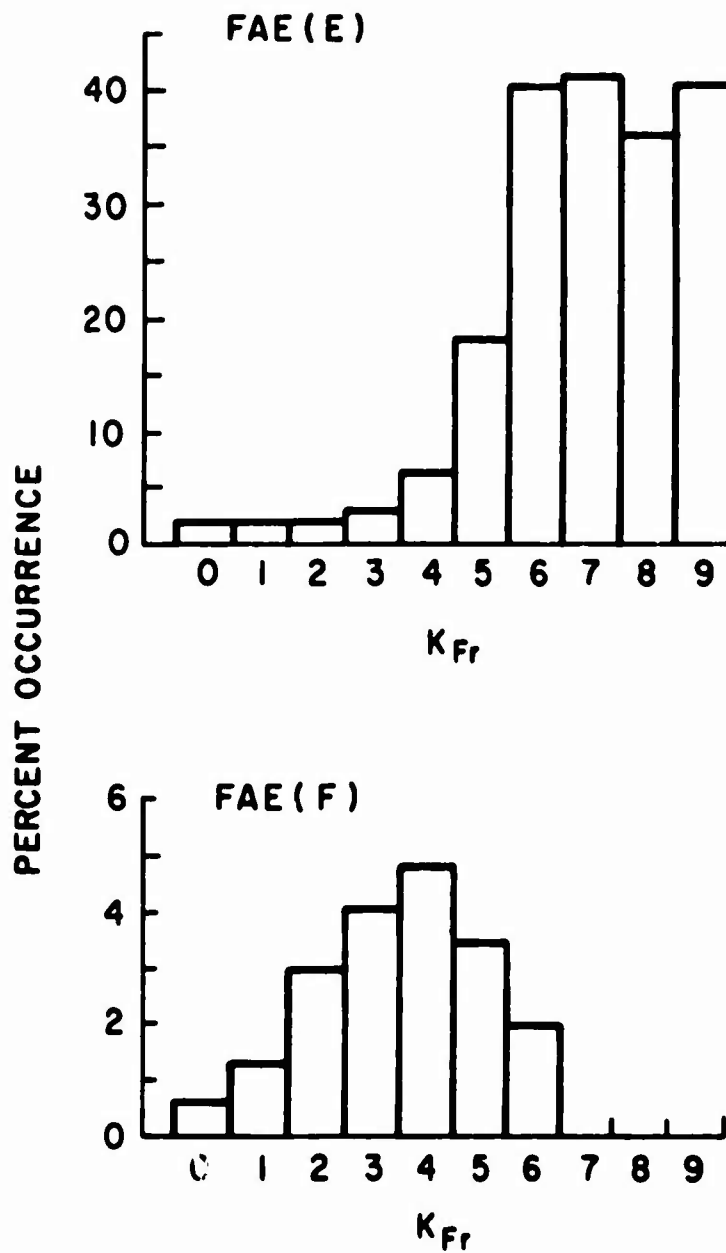


FIG. 15. FAE (E) AND FAE (F) AS A FUNCTION OF K_{FR}

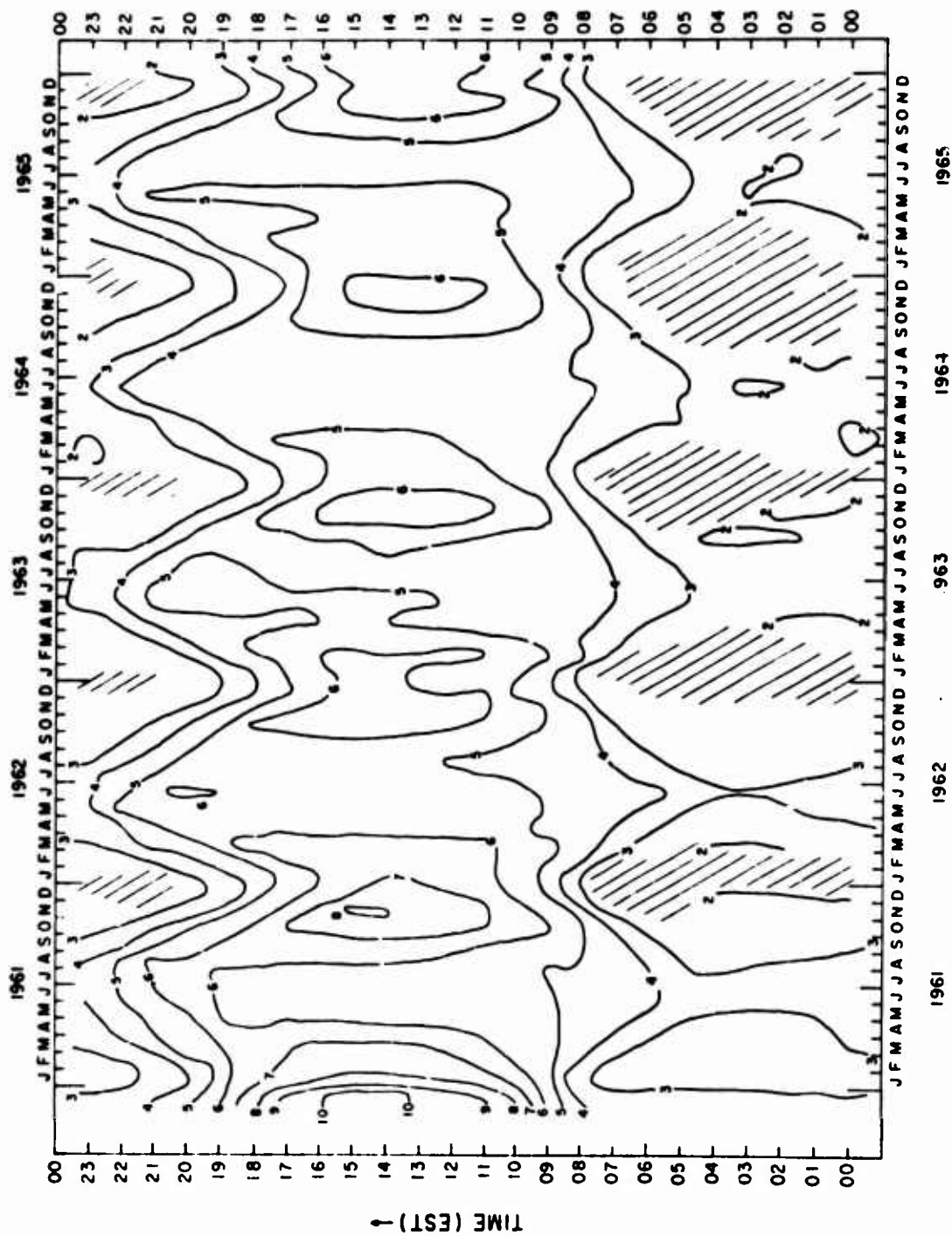


FIG. 16. MONTHLY MEDIAN f_0F_2 CONTOURS FOR WINNIPEG (KENORA AFTER OCT. 1963)

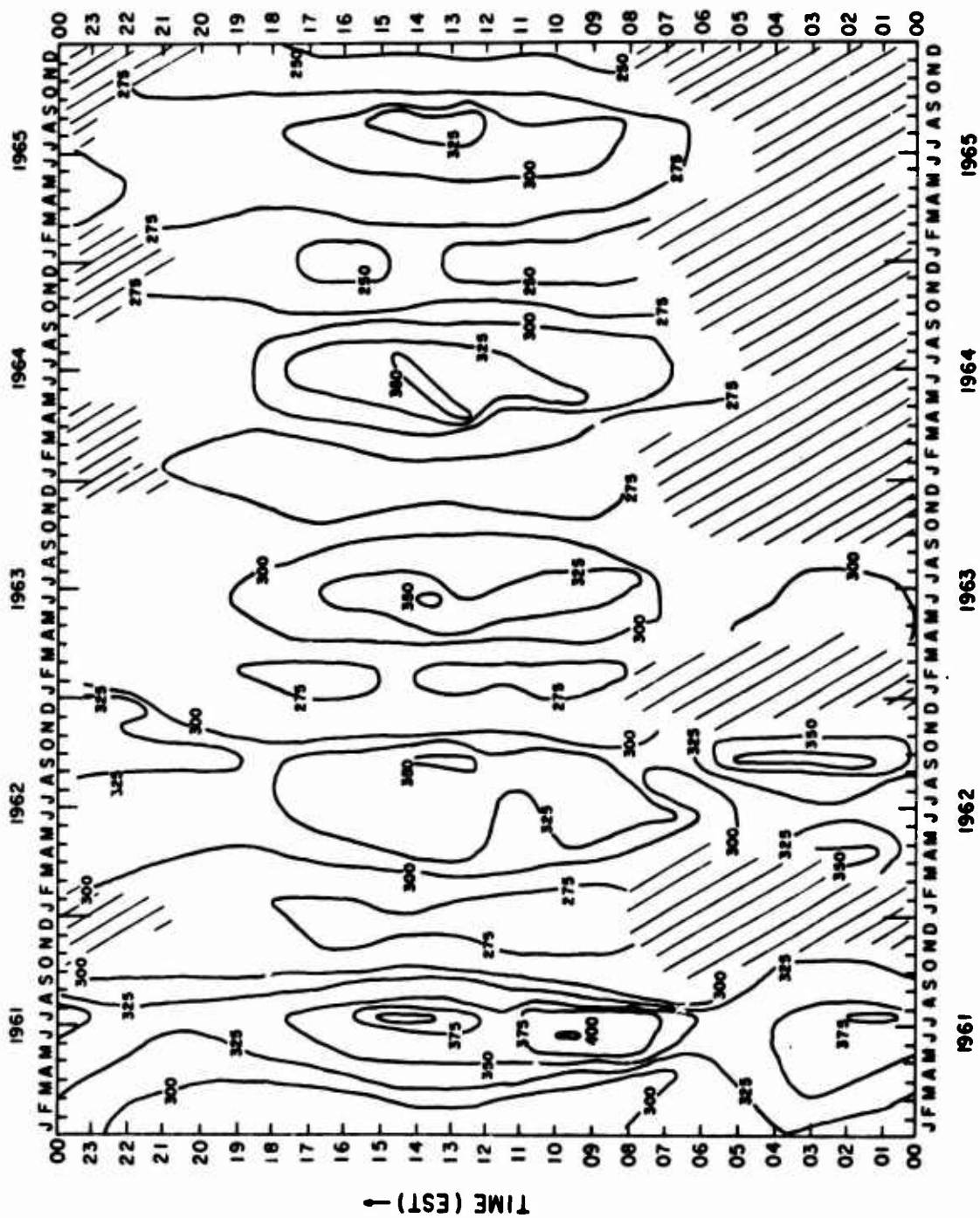


FIG. 17. MONTHLY MEDIAN M(3000)F₂ CONTOURS FOR WINNIPEG (KENORA AFTER OCT. 1963)

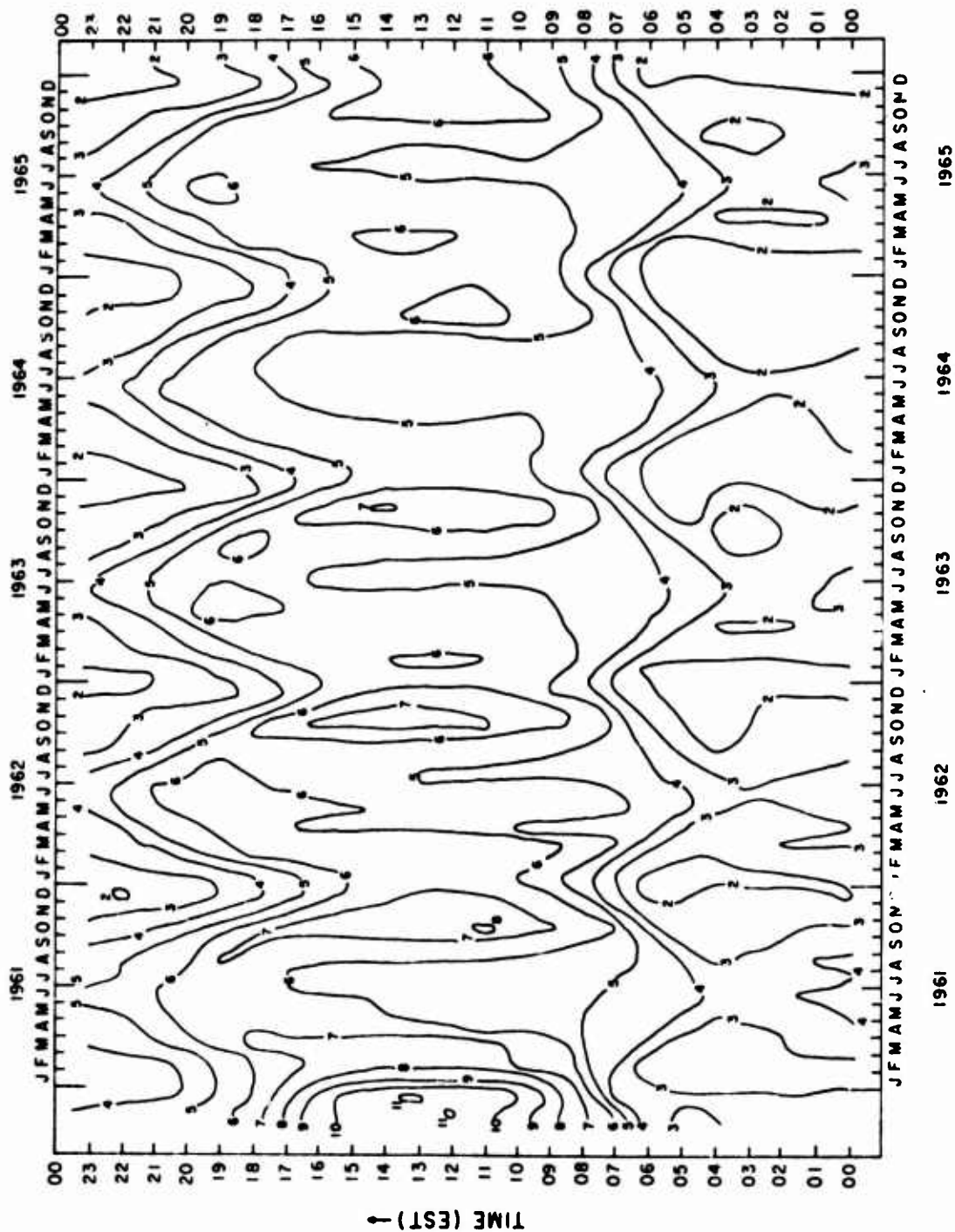


FIG. 18. MONTHLY MEDIAN f_0F_2 CONTOURS FOR ST. JOHN'S, NEWFOUNDLAND

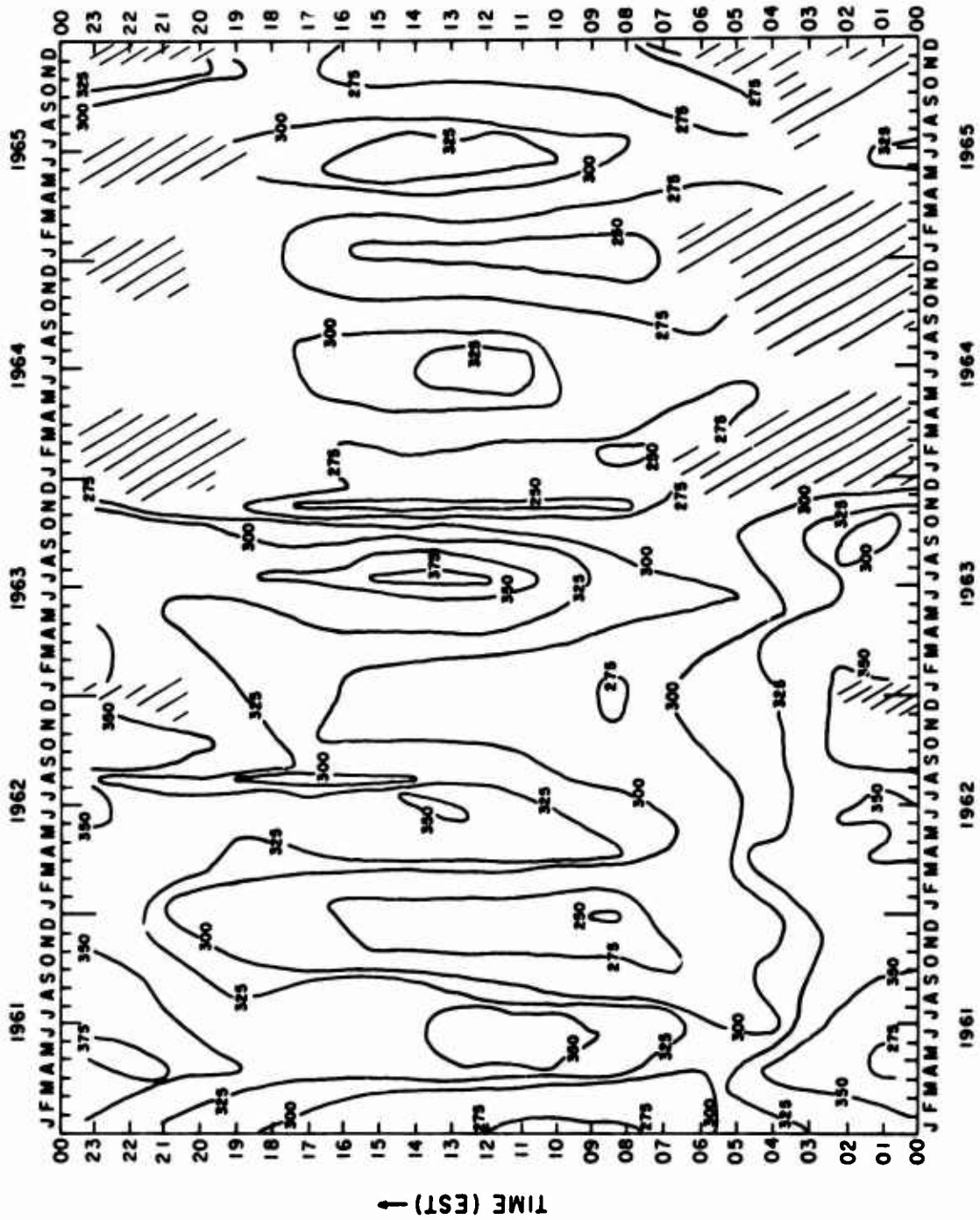


FIG. 19. MONTHLY MEDIAN $M(3000)F_2$ CONTOURS FOR ST. JOHN'S, NEWFOUNDLAND

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